Modeling the Stability of Martian Paleolakes

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Introduction: Recent studies have shown that ancient Martian paleolakes with initial depths greater than ~700 m could sustain brines for several years while the ice cap underwent sublimation [1]. While previous studies only explored the paleolake system in the presence of an ice cap, this work explores the complete system. The model described here takes into account the evaporation and freezing of water in the paleolake, the sublimation of ice, and the freezing and evaporation of the remaining brine. The effect of the decrease in solution activity over time and thus the decrease in the freezing temperature, freezing rate, and evaporation rate is of particular interest. Lower evaporation and freezing rates would indicate a longer brine lifespan and may explain thermal features such as crater floor polygons [2].

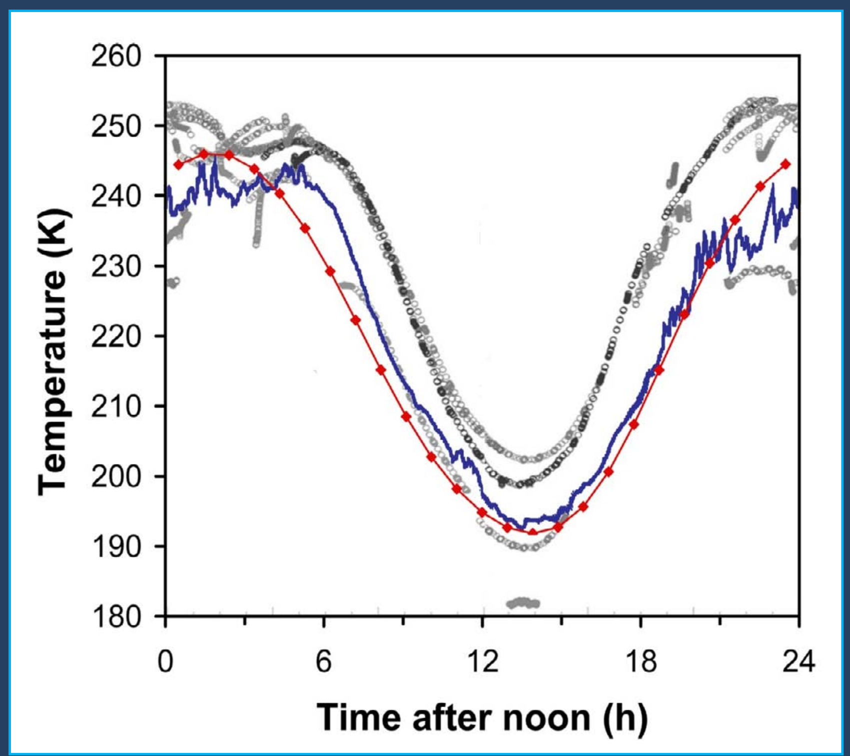

Figure 1 | Thermal Model Validation: Model of the temperature evolution for one Martian day at the Phoenix landing site (red) [1], compared to the data from the MET instrument 2 meters above the surface (blue) and data from the TECP in and near the surface (grey and black circles) [7].

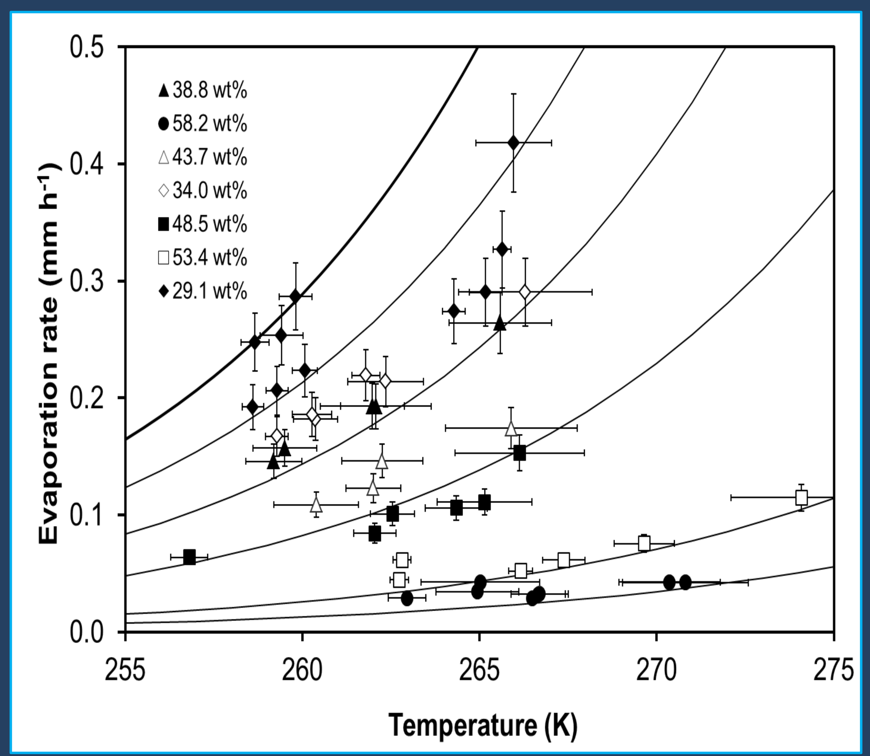

Figure 2 | Predicted vs. Observed Evaporation Rates of Brine: The evaporation rates predicted by equation 1 were plotted alongside experimental data given by Chevrier and Altheide, 2008 [4].

Brine	Thermal Conductivity [W/(m·K)]	Heat Capacity [J/(kg·K)]	Activity
1	0.6073	4133.16	0.9937
2	0.5790	3251.31	0.9543
3	0.5541	2918.355	0.8816
4	0.5470	2777.72	0.8525
5	0.5461	2851.97	0.8423
6	0.5510	3410.23	0.7350

Table 1: Thermal properties given for 6 brines by Tosca *et al.* [5].

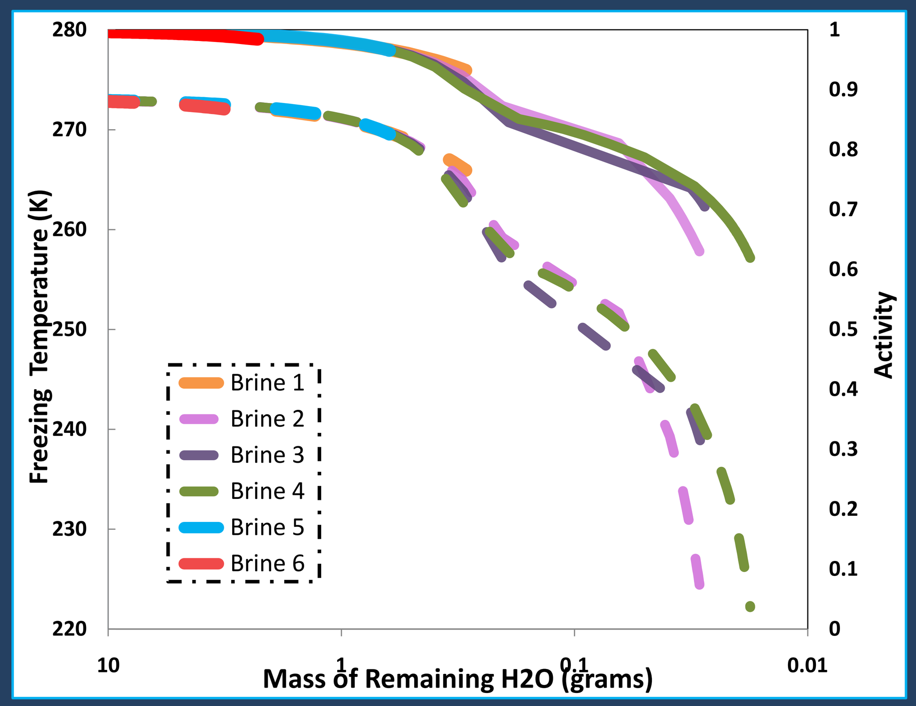

Figure 3 | Change in Activity and Freezing Temperature with Decrease in Solvent: The freezing temperature and activity of each of the six brines are plotted with varying concentrations of H_2O. The top cluster of lines (solid) represents the activities of the brines, while the bottom cluster (dashed) represents the freezing temperature of the brines. The initial mass of H_2O was 1 kg.

Methods

- Modeled 200m deep brine
- Only vertical diabatic transfer allowed
- System is well mixed

Equations

$$\frac{\delta T}{\delta t} = \frac{k}{\rho c}\frac{\delta^2 T}{\delta z^2}$$

Equation 1: Heat Equation; describes the conduction of heat through a material.

$$J = (0.17)\Delta\eta D\left(\frac{\frac{\Delta\rho}{\rho}g}{\upsilon^2}\right)^{\frac{1}{3}}$$

Equation 2: Ingersoll's Equation [3]; describes buoyancy controlled mass transfer of water under Martian conditions.

$$M_{H_2O\ i+1} = M_{H_2O\ i} - \rho_w R \Delta t b$$

Equation 3: Description of the the recursive loss of water.

$$T_f = \left(\frac{1}{T_0} - \frac{(R\ln a_{H_2O})}{\Delta H_{fus}}\right)^{-1}$$

Equation 4: Description of the freezing point temperature as a function of activity [4].

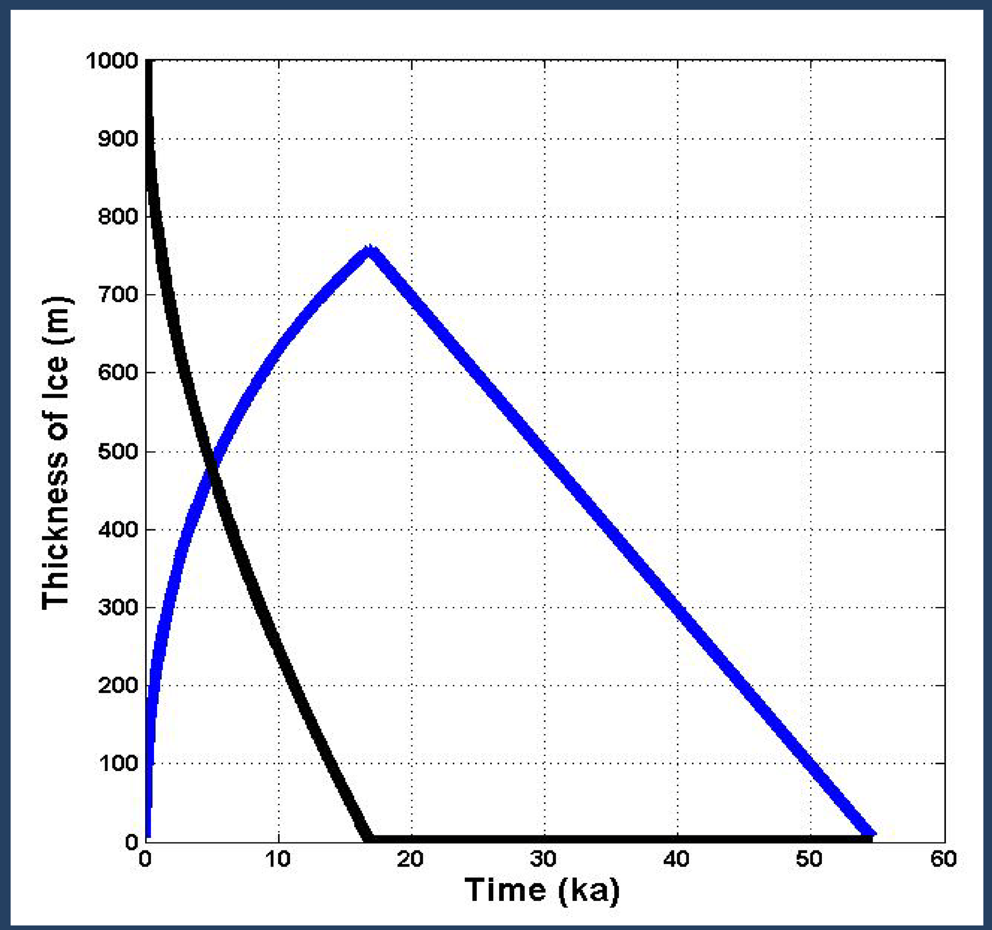

Figure 4 | Thickness of Water and Water-Ice with Time: The thickness of the ice cap (blue) is plotted alongside the thickness of the remaining liquid (black). This model incorporates freezing point depression as liquid water is removed from the system.

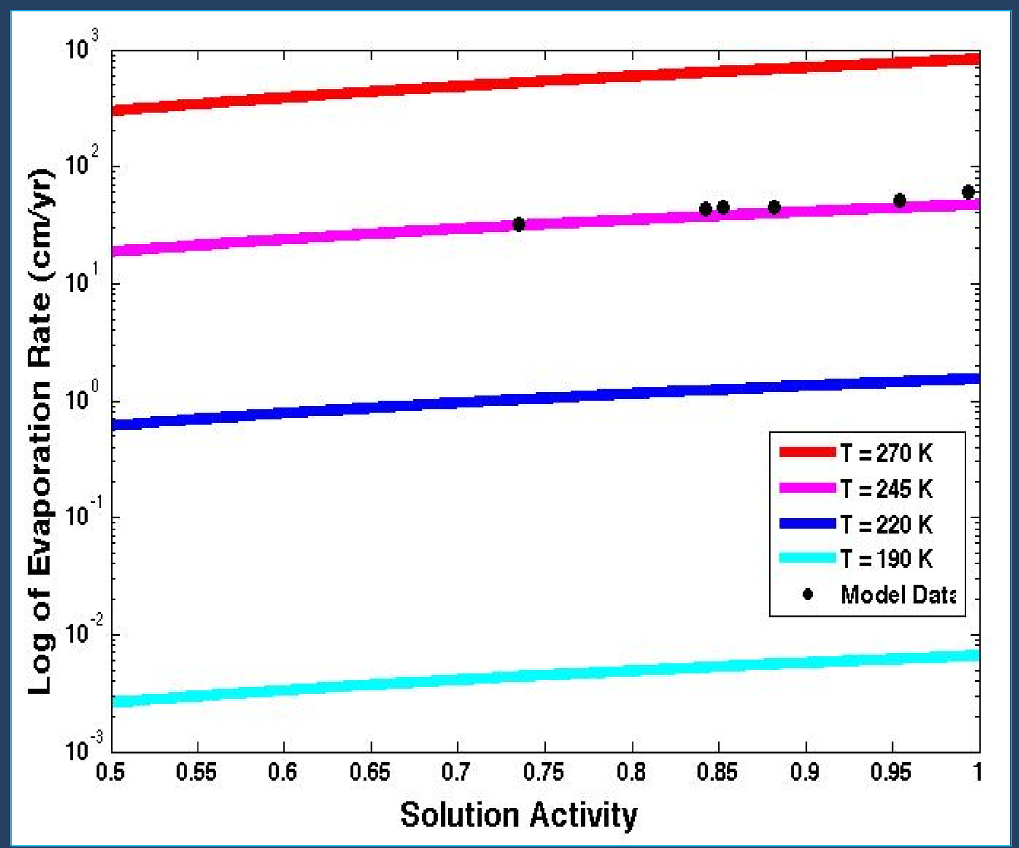

Figure 5 | Evaporation Rates for Brines of Different Activities: The evaporation rates of 6 brines, given by Tosca *et al.*, were found [5]. The cyan line represents the minimum average annual temperature on Mars, while the blue and orange lines represent the average annual and maximum average annual temperatures on Mars, respectively. A temperature of 245 K was fitted to these 6 data points and is graphed as the pink line.

Conclusions

- 200 meters of the most concentrated brine given by Tosca *et al.* produces brine lasting 620 years, assuming no phase change
- Brines 3, 4, and 5 could remain liquid on Mars for nearly half of every year
  - Freezing temperature of these brines is roughly the average annual temperature on Mars (220 K)
- Assuming large liquid bodies composed of Tosca *et al.*'s brines, the full phase change model predicts complete body freezing within 17 ka
  - Observing sublimation rates at Columbus Crater, this provides a lifespan of ~ 54 ka.
- Average annual temperature cannot be assumed when calculating evaporation rates
  - Temperature that fits data is above average annual and average maximum annual temperatures

Future Work

- Account for:
  - Salt Precipitation
  - Temperature variations in salt chemistry
  - Fully incorporate Geochemist's workbench with the main code.

Acknowledgements & References

Funding for this project was provided by the National Science Foundation, Award Number 0851150. | [1] Rivera-Valentin *et al.*, 2011. Effects of Freezing Point Depression on Martian Paleolake Stability. LPSC XXXVII, Abstract #1074. [2] El Maarry *et al.*, 2010. Crater floor polygons: Desiccation patterns of ancient lakes on Mars? JGR, 115, E100006. [3] Ingersoll, A. P., 1970. Mars: Occurrence of Liquid Water. Science, 168, 972-973. [4] Chevrier, V. F., Altheide, T. S., 2008. Low temperature aqueous ferric sulfate solutions on the surface of Mars. Geophysical Research Letters, 35. [5] Tosca *et al.*, 2011. Physicochemical properties of concentrated Martian surface waters. JGR, 116, E05004. [6] Wray *et al.*, 2011. Columbus crater and other possible groundwater-fed paleolakes of Terra Sirenum, Mars. JGR. 116, E01001. [7] Zent *et al.*, 2009. Thermal and Electrical Conductivity Probe (TECP) for Phoenix. LPSC XL, Abstract #1125.